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33. *A Strike-Slip Fault Buried in a Layered Medium.*

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Abstract

The author presents an improved fault model so as we may deal with faulting in a medium with a surface layer. For simplicity's sake in mathematical treatment, the model assumes a two-dimensional strike-slip fault which extends from the bottom of the surface layer vertically down to a certain depth. In practice, the author applies the relaxation method to obtain the solution for several examples with various rigidity contrast and thickness of the surface layer.

Crustal deformations associated with the Fukui earthquake seem to be attributed to a buried fault of strike-slip type. Comparison of the theory with the triangulation data proves that the present model explains the observations satisfactorily, if we apply the parameters properly.

1. Introduction

Recent progress in the study of fault mechanisms owes much to theoretical models introduced for the purpose of explaining crustal deformations around earthquake faults. To adapt these models to an actual fault, the respective authors synthesised the phenomena as simply as possible so that they could work out mathematical analyses easily. The first successful application of the model was effected with a group of strike-slip faults which seemed to extend from the earth's surface vertically down to a certain depth. The San Andreas and Gomura faults would be representative ones of this group[1].

Introduction of the dislocation theory to this research field has enabled us to establish advanced models[2]. Some of these models, for instance, can deal with a fault's shape and the force type more arbitrarily than the preliminary ones do, though not many examples along this line have yet been published. As to the other assumptions, however, the

1) *f. i.* K. KASAHARA, *Bull. Earthq. Res. Inst.*, **36** (1957), 455-464.
2) T. MARUYAMA, *Bull. Earthq. Res. Inst.*, **42** (1964), 289-368.

advanced models subject to the same restrictions as the preliminary ones. Homogeneity and perfect elasticity, for instance, still survive as the basic assumptions. Taking the complicated structures and properties of the earth's crust into consideration, the above-stated restrictions should be released as much as possible in order to establish a model for more general use.

2. Solutions by the relaxation methods

The basic idea of the present model is similar to the previous one[3] and is illustrated in Fig. 1. Let us assume that a semi-infinite elastic

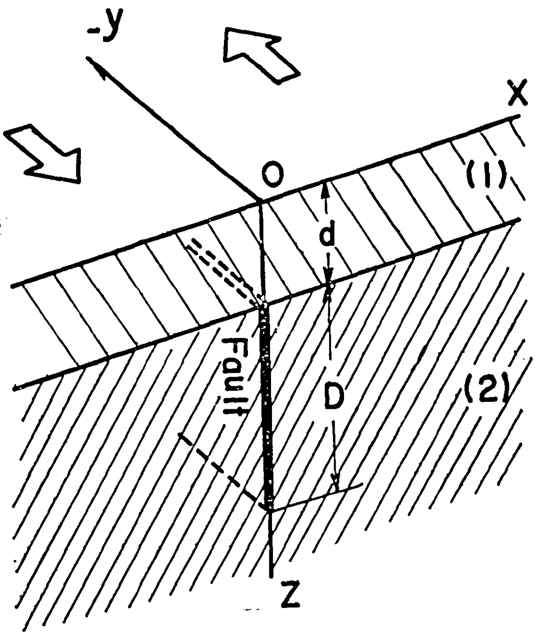

Fig. 1. Model of a buried fault.

medium with a surface layer of uniform thickness (d) is subject to uniform shear strain, initially. Faulting is represented, then, by production of a vertical plane of free surface, which extends from the bottom of the surface layer down to a certain depth ($z=d+D$). After simple consideration, we see that displacement of the medium takes place only in the y-direction and that the phenomenon is reduced to the problem of a pure shear field.

3) *loc. cit*, 1).

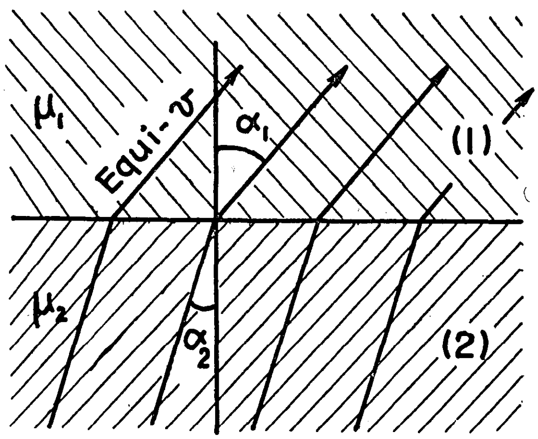

Fig. 2. Refraction of the equi-v lines across an interface.

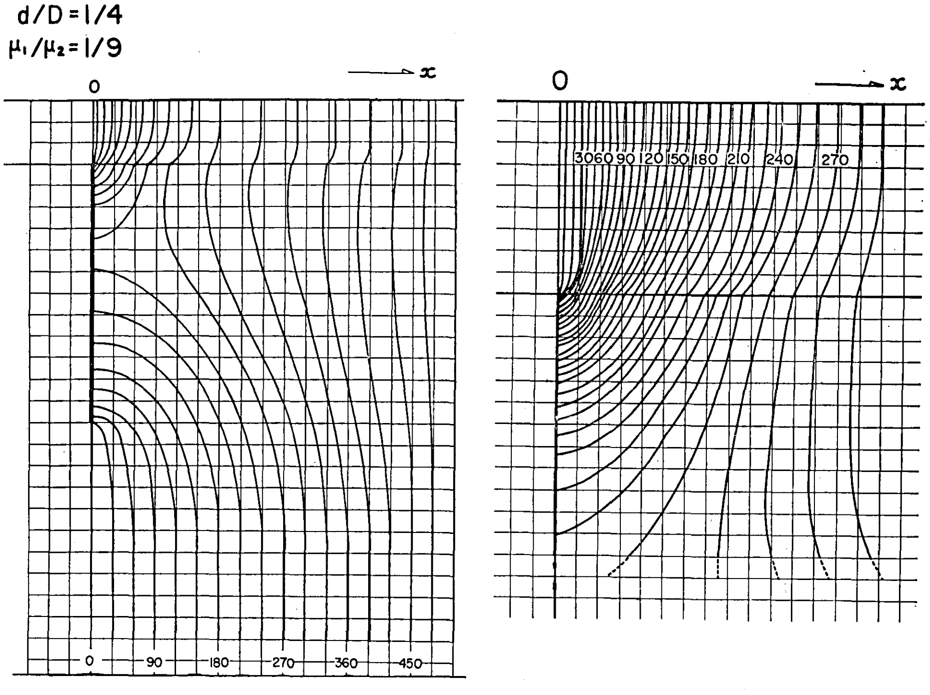

Fig. 3. Equi-v lines in relative value (left), and its partial pattern enlarged three times (right). $d/D=1/4$, $\mu_1/\mu_2=1/9$.

As previously discussed, this sort of problems can be solved conveniently by the relaxation methods taking the successive approximation so as the displacement component (v) may satisfy the Laplace equation as well as the necessary boundary conditions everywhere. It is not necessary for the author to repeat the basic mathematical equations, since the previous expressions can be used commonly by applying minor modifications. Conditions at the interface of the two media, however, need additional consideration as follows.

Let the parameters in the upper and lower media be distinguished by suffix 1 and 2, respectively. Then continuity of displacement and stress at the interface can be written as

$$v_1 = v_2 \ , \tag{1}$$

and

$$\mu_1(\partial v_1/\partial z) = \mu_2(\partial v_2/\partial z) \ , \tag{2}$$

respectively, where μ denotes rigidity. After simple consideration, we obtain,

$$\tan \alpha_1/\tan \alpha_2 = \mu_2/\mu_1 \ , \tag{3}$$

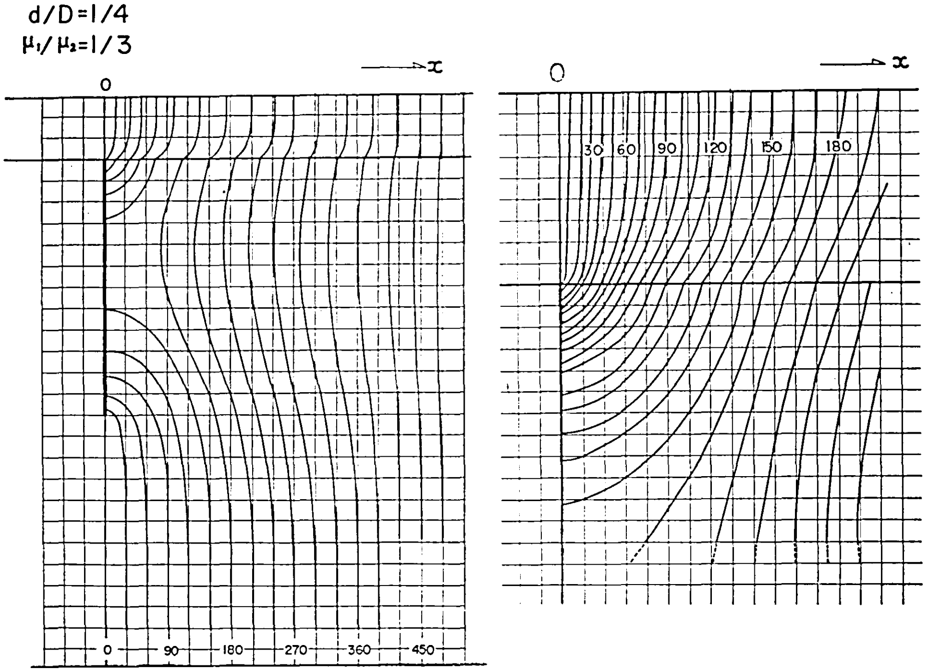

Fig. 4. Equi-v lines in relative value (left), and its partial pattern enlarged three times (right). $d/D=1/4$, $\mu_1/\mu_2=1/3$.

where, α denotes the angle between the normal to the interface and the equi-value line of v. Eq. (3) is similar to the refraction law of the line of electro-static force at an interface, if we replace the rigidity by the inverse of the dielectric constant. That is to say, the present problem can be solved by the relaxation methods analogously to an electrostatic field[4].

In practice, the author replaced the medium by a square relaxation net of unit side-length, s. Numerical solutions are obtained for the three different values of μ_1/μ_2 as illustrated in Figs. 3—5, where d and D are fixed at $3s$ and $12s$, respectively. In Fig. 3, which represents the case of very low rigidity of the surface layer ($\mu_1/\mu_2=1/9$), the upper part of the base medium is subject to large disturbances, indicating weak resistance of the surface layer against deformation. In order to observe the deformation directly associated with the faulting, it is necessary to subtract the initial shear strain from the figure. Fig. 6 is drawn in this way and illustrates the amplitude of v at the surface.

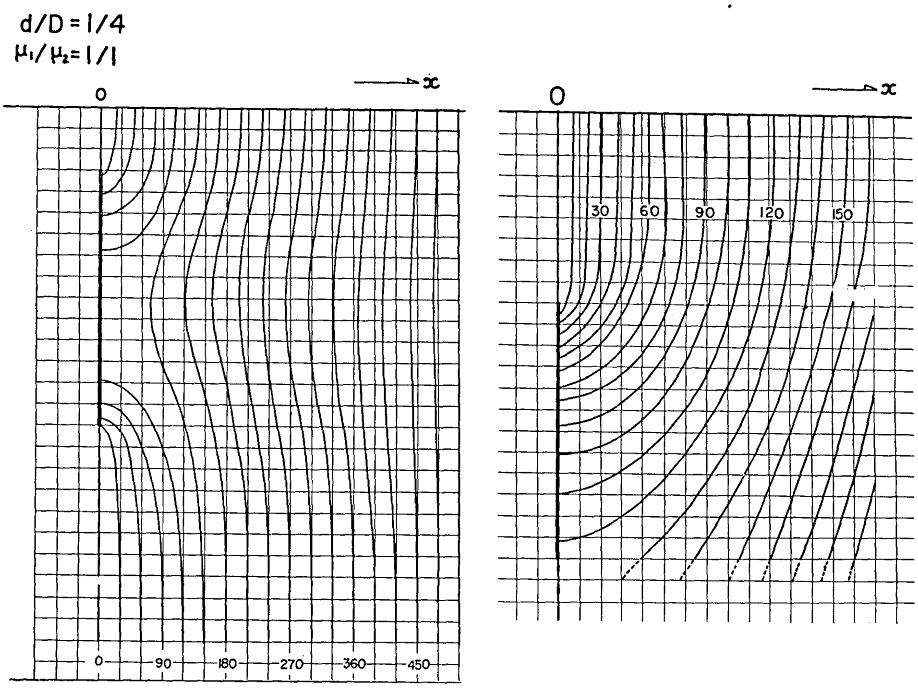

Fig. 5. Equi-v lines in relative value (left), and its partial pattern enlarged three times (right). $d/D=1/4$, $\mu_1/\mu_2=1/1$.

4) R. V. SOUTHWELL, *Relaxation Methods in Theoretical Physics I* (1946), p. 89.

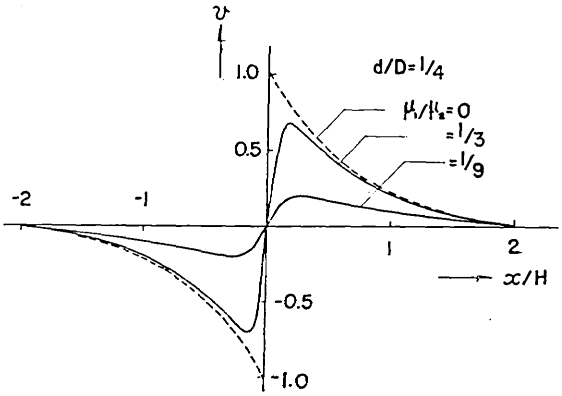

Fig. 6. Distribution of v along the surface of various models.

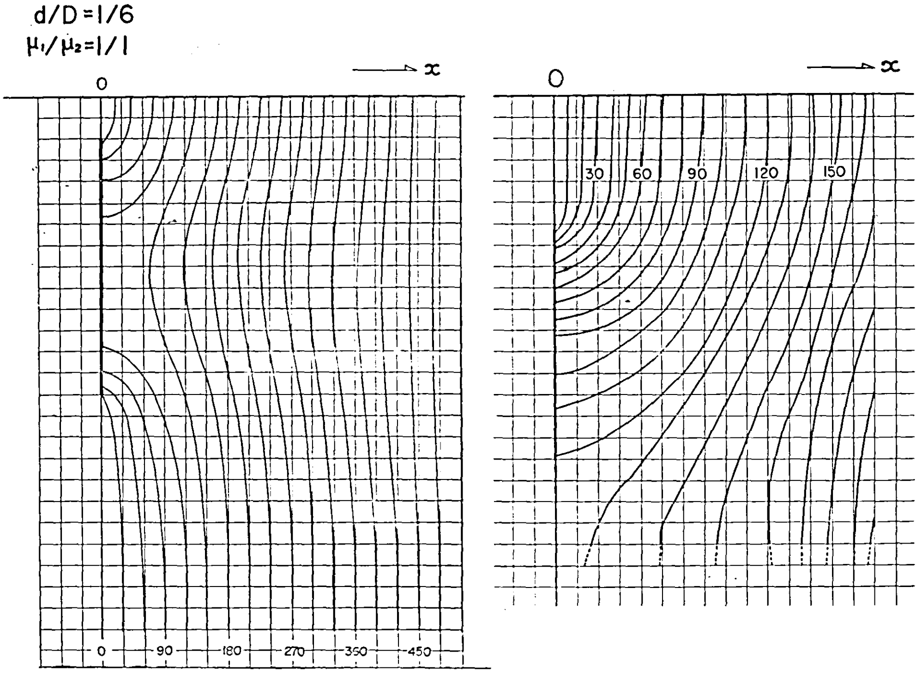

Fig. 7. Equi-v lines in relative value (left), and its partial pattern enlarged three times (right). $d/D=1/6$, $\mu_1/\mu_2=1/1$.

The more the rigidity ratio approaches 1/1, the stronger becomes the resistance of the surface layer, resulting in less disturbance at the surface. We notice this tendency clearly by comparing Figs. 3—5 with each other. In Fig. 5, which represents the case of $\mu_1/\mu_2=1/1$, the maximum value of v in the fracture plane reduces to a value almost half of that in Fig. 3. As a result, deformation of the surface is very small in comparison with the first two cases (Fig. 6).

We may say that Fig. 5 represents a fault buried in a homogeneous medium, since the surface layer has the same rigidity as the lower one. For the purpose of examining the influences of the fault's depth, examples in Figs. 7 and 8 are added by taking various values of d, whereas μ_1/μ_2 and D are kept unchanged.

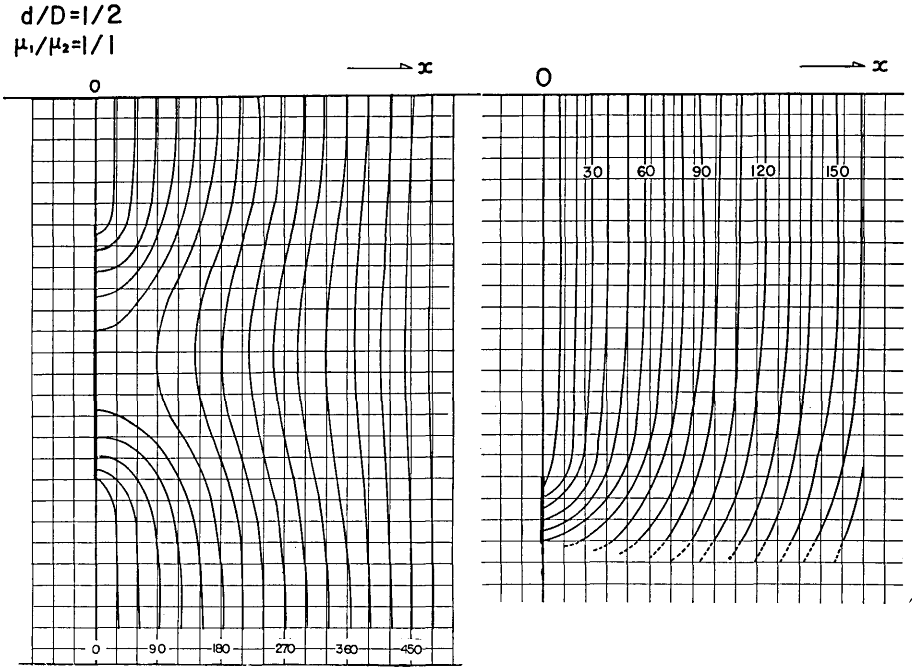

Fig. 8. Equi-v lines in relative value (left), and its partial pattern enlarged three times (right). $d/D=1/2$, $\mu_1/\mu_2=1/1$.

3. Crustal deformations associated with the Fukui earthquake of 1948

Possibility of buried faults has not been established without some doubt, though speculative considerations have been made by several tectonophysicists who explained a certain type of the earth's deformations by block movements or faults occurring under thick alluvium layers[5]. It is unfortunate that we have no good example of buried

5) Y. OTUKA, *Chishitu-Kōzō to Sono Kenkyū* (Hōbundō, 1952), pp. 184–186 (in Japanese). S. MIYAMURA and A. OKADA, *Bull. Earthq. Res. Inst.*, **34** (1956), 373–380 (in Japanese).

faults to compare with models as presented above.

As far as the author is aware, however, crustal deformations associated with the Fukui earthquake might be the only case that seems to be explained by the present model. The seismometrical parameters of the shock, which took place on June 28, 1948, were reported as follows[6].

Epicenter : 36°08′ N, 136°16.8′ E
Depth : 33 km
Magnitude : $7\frac{1}{4}$

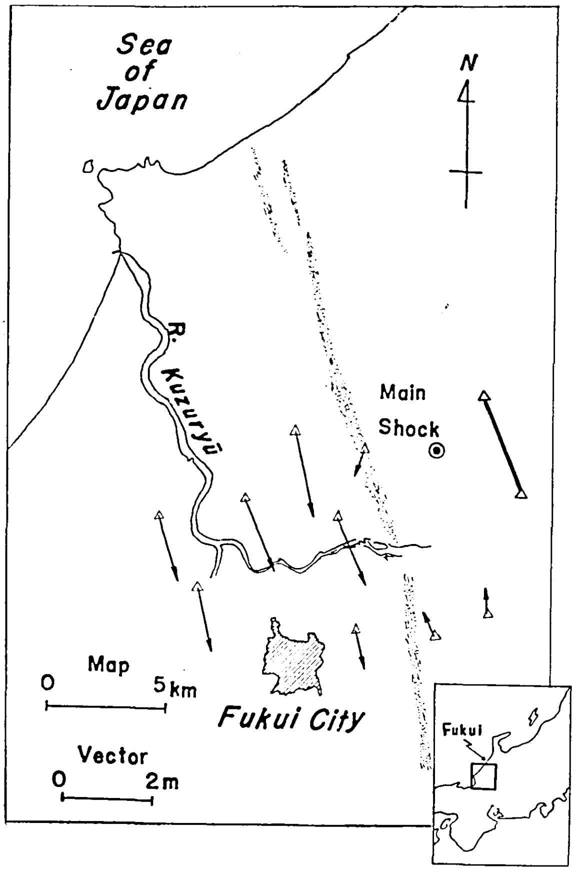

Fig. 9. Crustal deformations observed around the epicenter of the Fukui earthquake[7]. Direction, length and position of the thick straight line was tentatively assumed to be unchanged.

6) H. TSUYA (*Editor*), *Report of the Special Committee for the Study of the Fukui Earthquake*, pp. 1-28.

Its focal mechanism is explained very well by the so-called quadrant-type pattern, with a pair of nodal lines in the directions of N 10° W and N 80°E, approximately. So far as this kind of information is concerned, the Fukui earthquake seems similar, in various aspects, to the Tango earthquake (1927), which was accompanied by the famous Gomura fault. In fact, macroseismic field surveys made after the present shock revealed that a narrow zone across the epicentral area was subject to numerous small fissures as illustrated in Fig. 9.[7] These events are so small in scale that we can hardly conclude the zone as an earthquake fault, although it extended in the same direction as one of the nodal lines mentioned above. Another notable fact was discovered by triangulations which were resurveyed after the shock by the Geographical Survey Bureau. Arrow marks in Fig. 9 represent horizontal displacement of triangulation stations thus obtained. Location of the two triangulation stations, which are connected by a thick straight line, are assumed unchanged between the two surveys. The arrows' pattern, which shows systematic orientation and amplitude variation in space, seems to suggest that the land on the west side of the zone shifted to the direction of N 10°W relatively to the land on the opposite side.

To see this tendency more clearly, amplitudes of the vectors are plotted in Fig. 10 as a function of the distance from the fracture belt, where the x-coordinate is shifted to some extent so as the distribution of the plotted data looks antisymmetric with respect to the origin of the

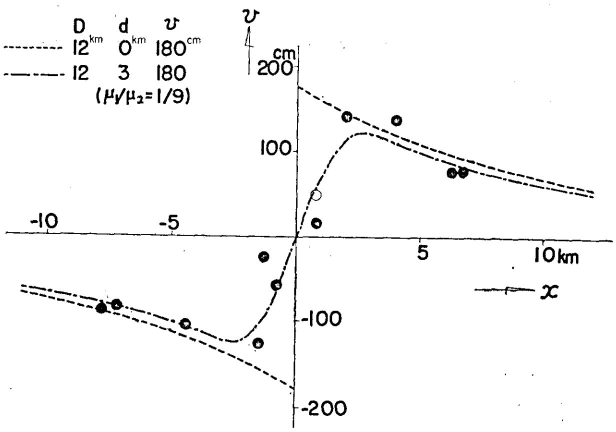

Fig. 10. Theoretical curve of v of a buried fault model as compared with the observations.

7) *ibid.*, 113.

coordinates. It is interesting to compare the distribution with the theoretical curves of various models. The broken line in the figure represents the previous model, in which the fault plane is assumed to extend from the surface down to a depth of 12 km. The observation shows evident disagreement with the curve in the central part of the figure.

The chain line represents, on the other hand, a buried fault model, the parameters of which are assumed as given in the same figure. It is notable that the latter curve explains the observation much better than the former. The author considers, however, that the present set of parameters is not the final solution though it might be one of possible solutions. This is because the retriangulation was conducted only in a limited area, too narrow to observe diminution of the v-x curve accurately. From this point of view, one may explain the observations equally well by taking a much larger value of D and changing the remaining parameters properly.

A similar comment can also be given on the value of d, which is taken as 3 km in the present solution. This is too large as a probable thickness of an alluvium layer even if we take all the permissible favorable conditions. The author is unable to provide an alternative explanation for its physical meaning, and he would like to postpone the solution for future studies. In connection with this question, however, he would like to refer to an interesting report at the termination of this paper. According to S. Omote and others[8] who worked out temporary field observations of aftershocks, the majority of the shocks occurred in the crust deeper than a few kilometers, which is the figure close to the thickness of the surface layer taken in the above-mentioned model.

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33. 横辷り型潜在断層

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従来は均質弾性媒質に限られていた断層模型の適用範囲を拡張する目的で，一つの表層をもつ媒質内部に断層が出現する場合の変形を緩和法によつて取り扱つた．ただし，断層は二次元的横辷り型のものであり，表層の底部から垂直下方に，一定の深さまで延びているものとする．

このような模型について，断層の深さ(幅)に対する表層の厚さを一定に保ちつつ二層の剛性率比を変化させた場合，および剛性率比を 1/1 に保ちながら表層の厚さを変化させた場合の数例について数値解を求めた．後者は，均質半無限弾性体の内部に断層が潜在する場合に相当するわけで，

8) *ibid.*, 57.

既に知られている dislocation 模型を数値的に扱うことにより結果を比較検討することができる筈のものである.

今回の模型を具体的に適用できる実例が豊富でないのは残念であるが, 1948年の福井地震に伴つた地殻変動については, それが横辷り型潜在断層によるものかと想像させるいくつかの観測事実がある. この意味で震央地域における三角点の水平移動の分布を模型と比較することを試みた. 限られた測量資料からでは確定的な解を求める訳には行かないけれども, 模型のパラメータを適当に選ぶことによつて観測事実の大局的な特徴はかなりよく説明できるように見える.